Biodiesel Production from Algae Growing on Municipal Wastewater: Turning a Nuisance (algae) into Biodiesel

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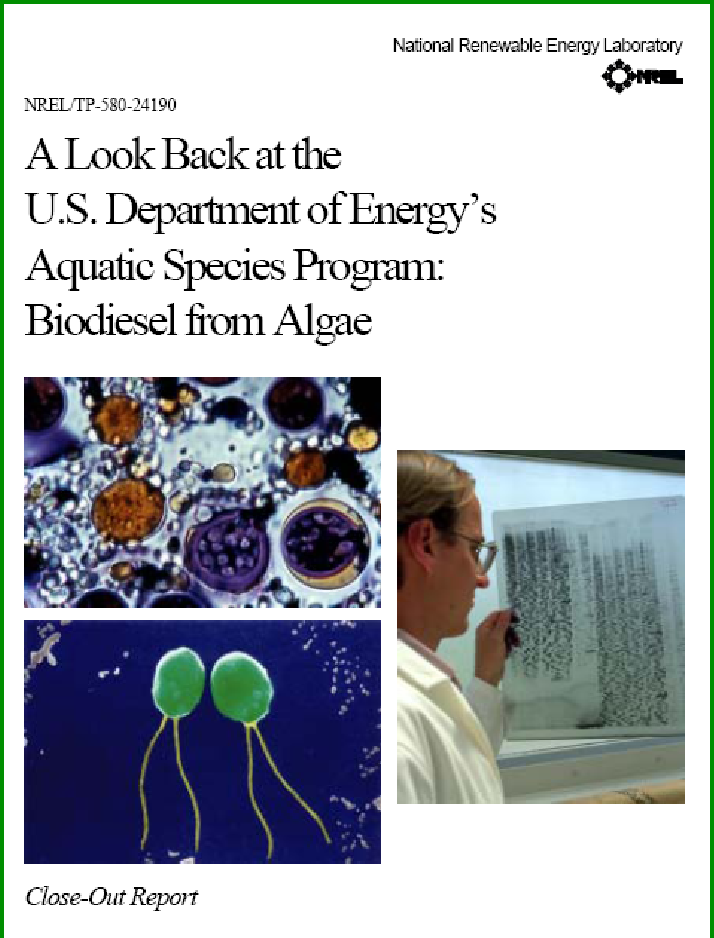
May 13, 2008 Climate Change Commission
George Mason University, Fairfax, VA

http://www.vcerc.org/

Biomass from Algae for the production of biodiesel


National Renewable Energy Laboratory

NREL/TP-580-24190

A Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae

Close-Out Report

Estimated cost: $1.40 to $4.40/gal

Or

$60 to $100 per barrel of oil equivalent

7.5 billion gallons of biodiesel per year requires 500,000 acres of water

Virginia Coastal Energy Research Consortium

Old Dominion University
Virginia Tech-ARL
University of Virginia
James Madison University
Virginia Commonwealth University
Norfolk State University
William & Mary (VIMS)
Hampton University

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Mission and Specific Strategies

Mission: The mission of the Virginia Coastal Energy Research (Working Group) is to identify and develop new coastal energy resources through multidisciplinary research collaborations and environmentally responsible strategies.

Strategies: Conduct research in areas consistent with a ***diversified portfolio*** of energy sources in coastal areas and offshore

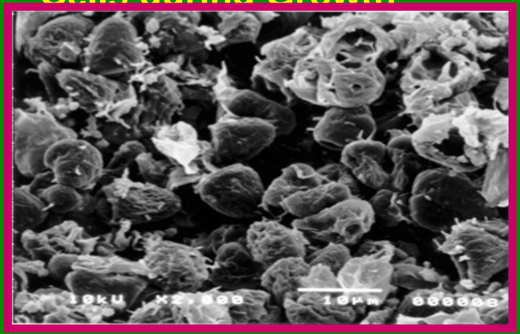
Initial focus:

1. Offshore wind and wave energy
2. Coastal Biomass for Biodiesel Production

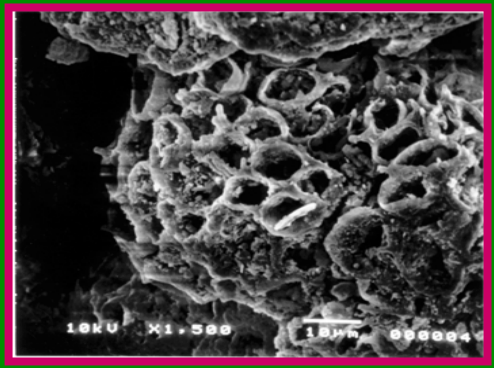
Why is biodiesel from algae attractive ?

1. **Algae are the original source of petroleum**

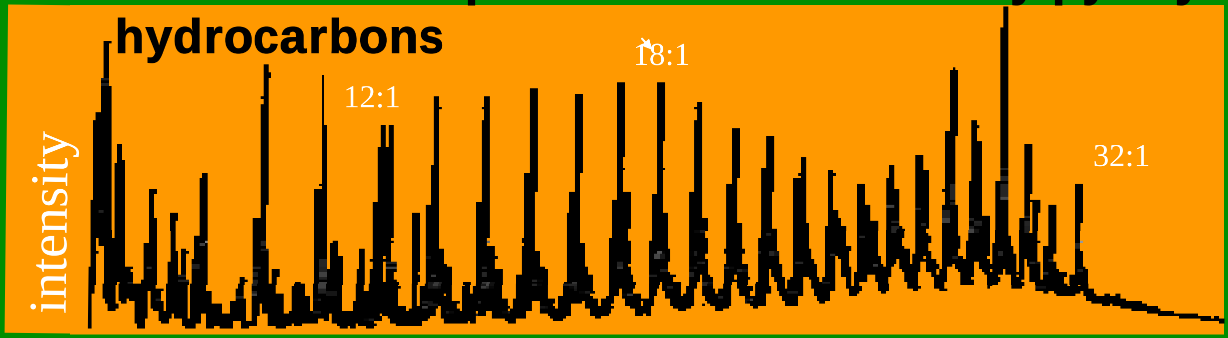
Cells during Growth



4-Million-Year-Old Fossilized Cell Walls



2. **If we simulate petroleum formation by pyrolysis, we produce hydrocarbons**



Pyrolysis/GC/MS chromatogram of algae

3. **that resemble petroleum**

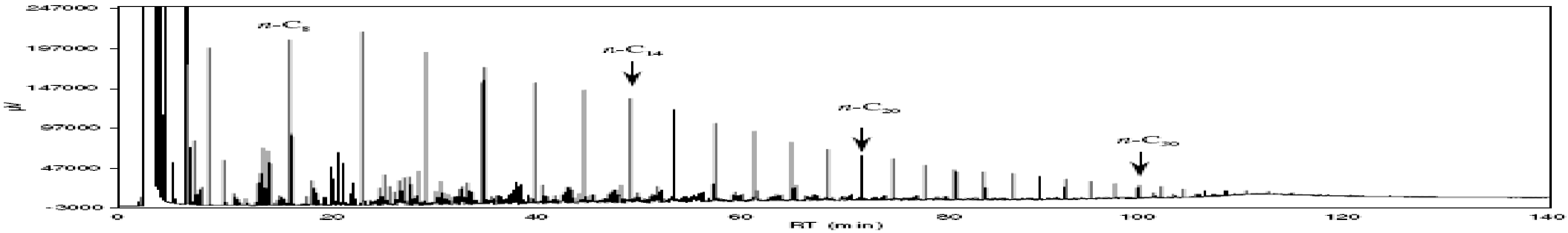


Fig. 1. GC trace of the total Safaniya oil.

Why Is It Attractive?

1. Algae outperforms all other plant-based sources of alternative fuels

Gallons of Oil per Acre per Year

Corn	15
Soybeans	48
Safflower	83
Sunflower	102
Jatropha	175
Rapeseed	127
Oil Palm	635
Microalgae*	1,850
Microalgae**	5,000 – 15,000

% of Agricultural Land Required to Fuel US Transportation

CORN	1,700 %
SOYBEANS	650 %
CANOLA	240 %
JATROPHA	154 %
COCONUT	108 %
OIL PALM	50 %
MICROALGAE	2 – 5 %

2. Does not require agricultural land, competing with farm crops

* Actual biomass yields ** Theoretical biomass yields

Oil Content of Some Microalgae

Microalga	Oil Content (% dry wt)
Botryococcus braunii	25–75
Chlorella sp.	28–32
Crypthecodinium cohnii	20
Cylindrotheca sp.	16–37
Dunaliella primolecta	23
Isochrysis sp.	25–33
Monallanthus salina	>20
Nannochloris sp.	20–35
Nannochloropsis sp.	31–68
Neochloris oleoabundans	35–54
Nitzschia sp.	45–47
Phaeodactylum tricornutum	20–30
Schizochytrium sp.	50–77
Tetraselmis sueica	15–23

From : Chisti, Y. 2007. Biodiesel from microalgae. *Biotechnology Advances* **25** 294–306

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Why is it attractive?

3. Algal production and ensuing biodiesel can be coupled with numerous industrial processes

a. Electric power generation to reduce CO_2 emissions- carbon credits (algae need CO_2 as a carbon source to grow)

b. Agricultural and municipal wastewater runoff to clean up nutrient-laden effluents (algae require the nutrients such as ammonia, phosphates, and nitrates for growth)

c. Clean-up of algae from eutrofied waterways-can pump and filter algae for use as a feedstock for biodiesel

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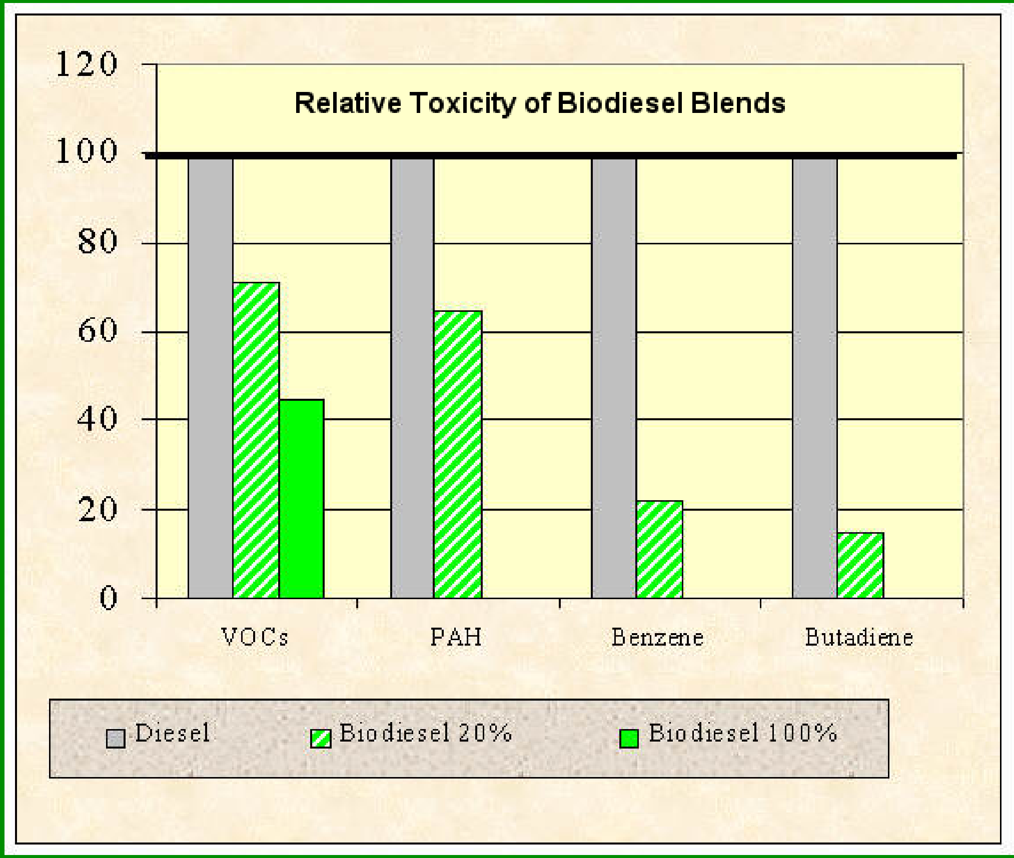
Why is it attractive?

4. Is cleaner burning, has less soot emissions (health issue), and is as efficient as a fuel compared to petroleum diesel



Why is it attractive for Virginia?

1. VA has plenty of sunshine

2. VA has many coastal areas amenable to locating algal ponds in close proximity to power generating facilities, municipal wastewater facilities and agriculture

3. VA's coastal waterways are choked with algae which could be removed and used as biodiesel feedstock while cleaning up the waterways

4. VA has the customers:
    1. Military
    2. Coastal cities with high energy demands
    3. US and State government buildings and vehicles

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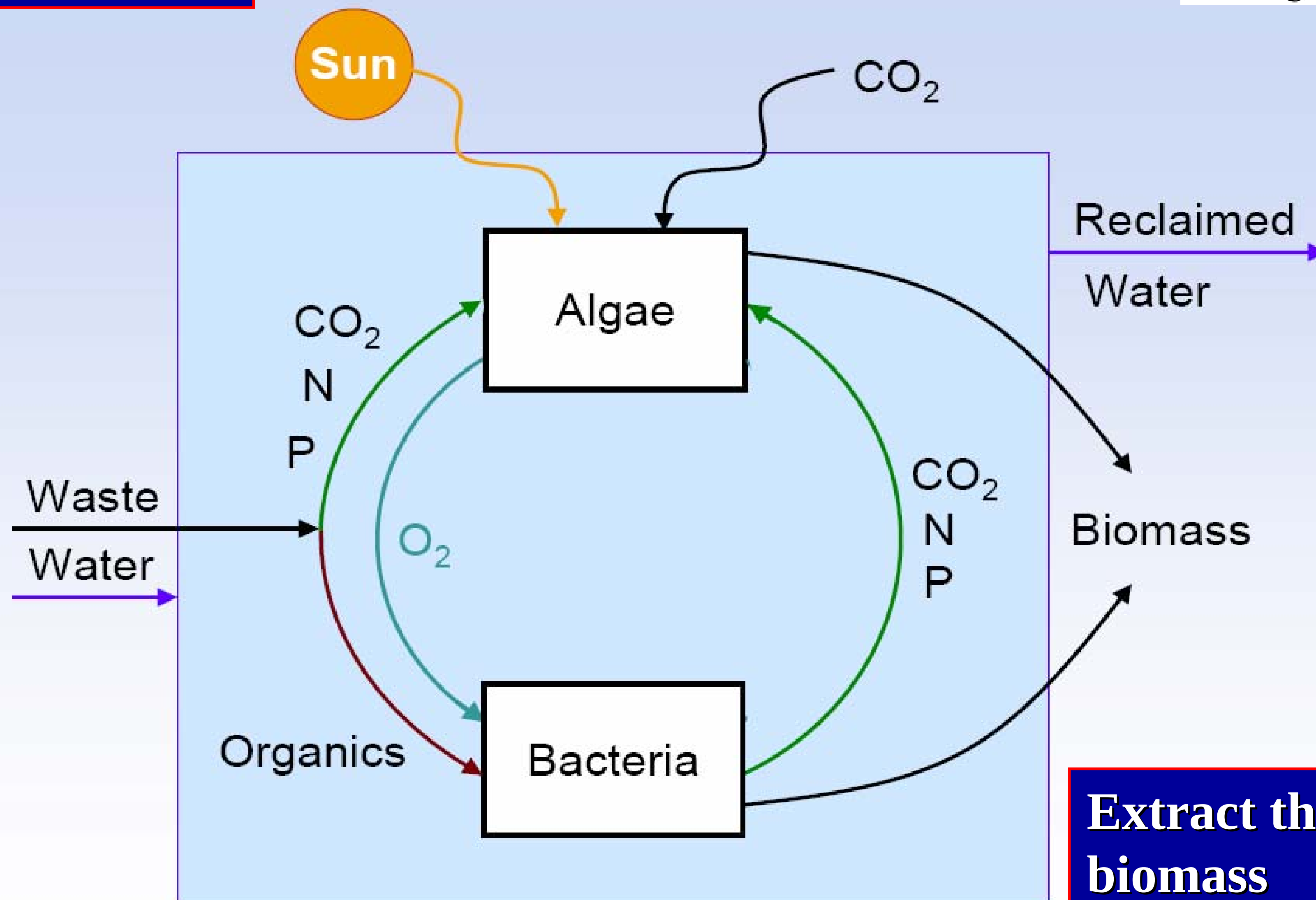
How It Works….

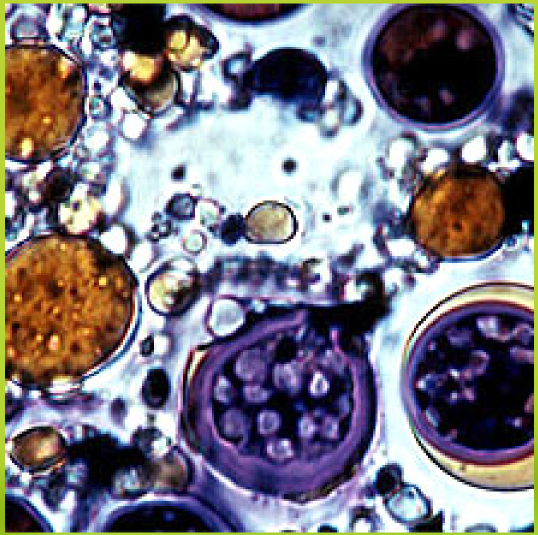
Grow the Algae



Extract the biomass

How It Works….

Extract the biomass



Extract the lipids = "bio-crude" oil

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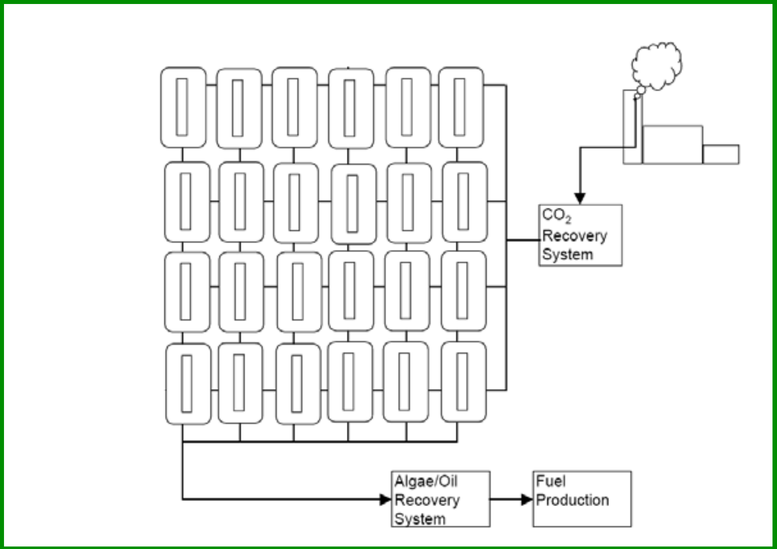
How It Works….

Refine into bio-diesel and other products

VCERC's strategy for the production of biodiesel from algae

Various options for design of production facility

1. **Coupled to agricultural effluents**
2. **Coupled to waterway cleanup (municipal wastewater facility)**
3. **Coupled to electricity generation**



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Wastewater interfaces for bioreactor

- **Free tertiary treatment**
  - **Alternative solution for meeting new nutrient discharge criteria**
  - **Potential sale of biofuels produced**
  - **Potential sale of nutrient credits generated through nutrient reductions**
- **Algal biomass from recycled nutrients, CO_2 and organic matter**
  - **Effluent nutrients stimulate algal growth**
  - **Potential boost in lipid production from heterotrophic growth**
- **Use available/adaptable technologies**
  - **Take advantage of continuous high nutrient flow**
  - **Harvesting technologies**

Test Facility:

Virginia Initiative Plant

Hampton Roads Sanitation District

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What We Are Currently Focusing On

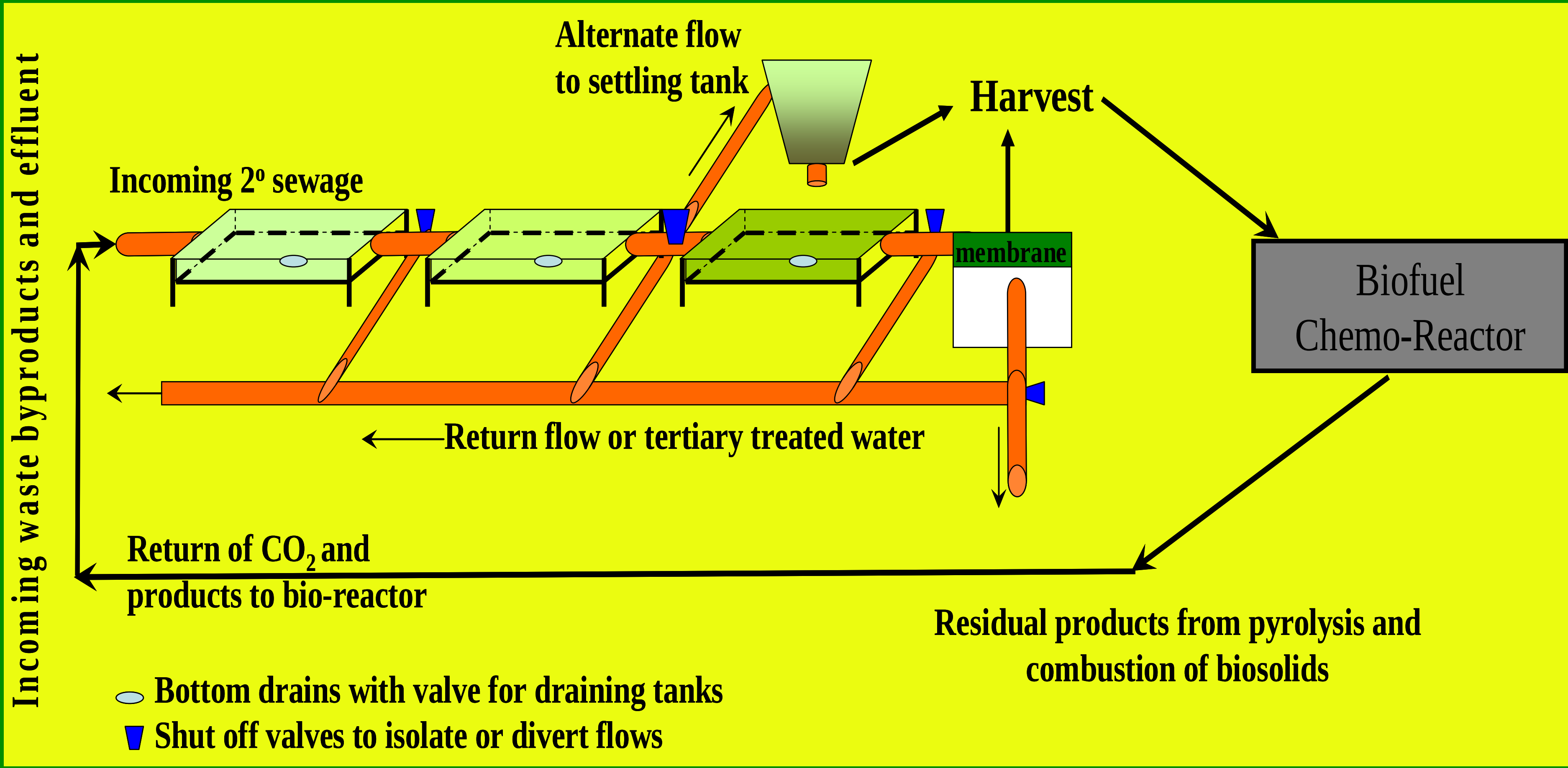
Interfacing

Optimizing

Design Solutions

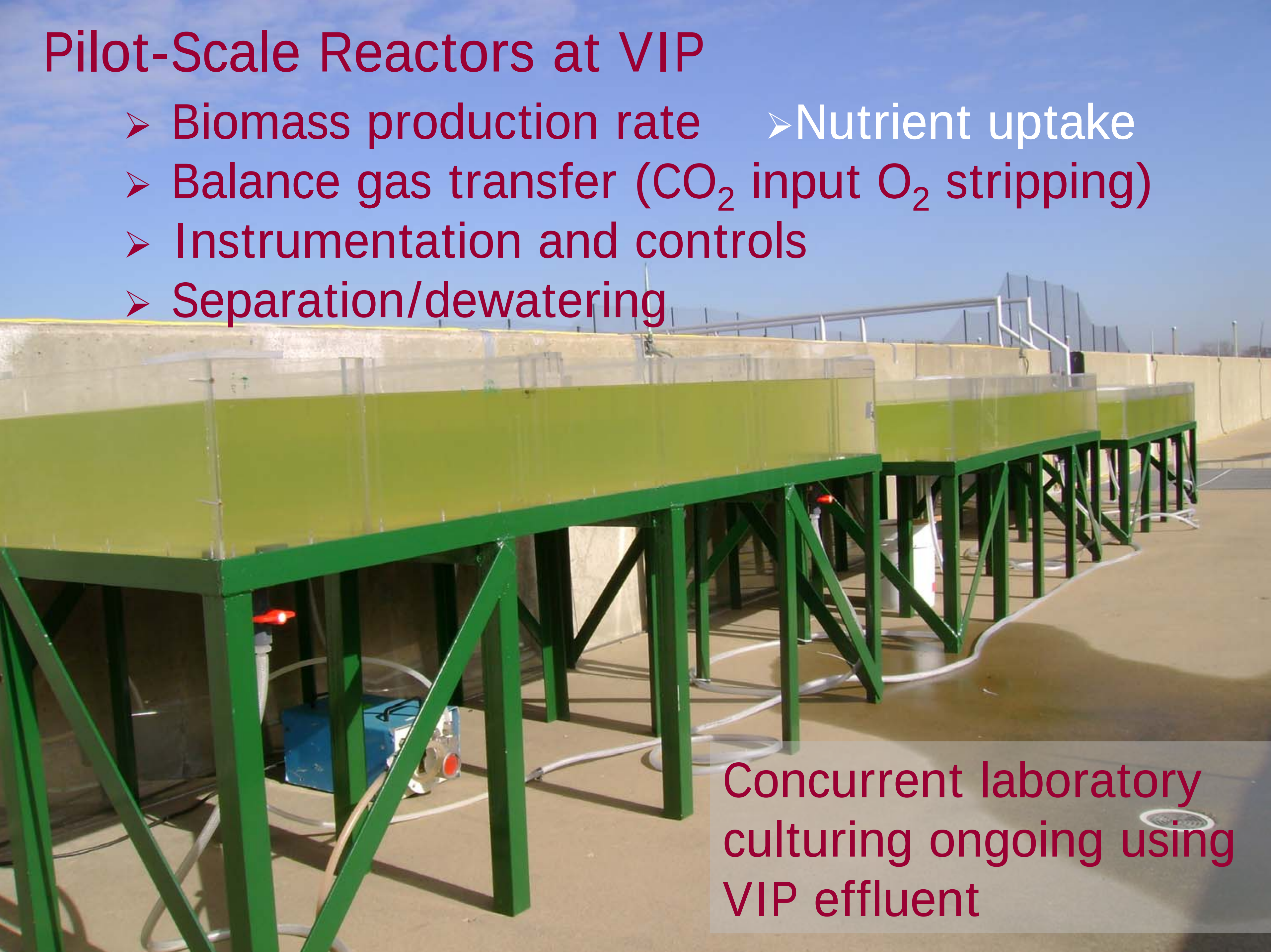
Scaling

Bio-Reactor :
production of algal biomass for conversion to biodiesel



Pilot-Scale Reactors at VIP

- Biomass production rate
- Nutrient uptake
- Balance gas transfer (CO_2 input O_2 stripping)
- Instrumentation and controls
- Separation/dewatering



Concurrent laboratory culturing ongoing using VIP effluent

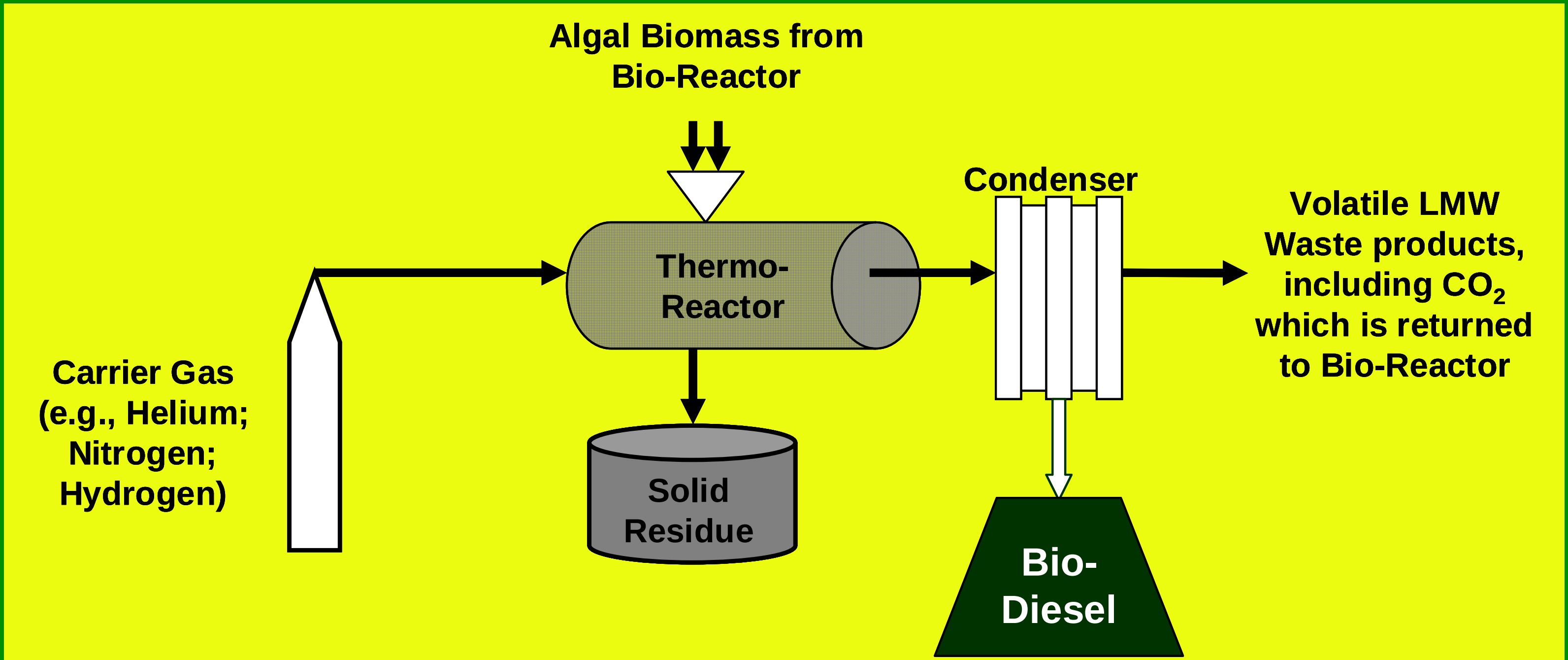
Strategies for conversion of algal biomass to biodiesel

1. Traditional

algae → Extract oil from algae → Treat with alkali (lye) and methanol → Transesterified fatty acids (biodiesel)

2. Alternative

algae → Treat directly in chemoreactor → Biodiesel



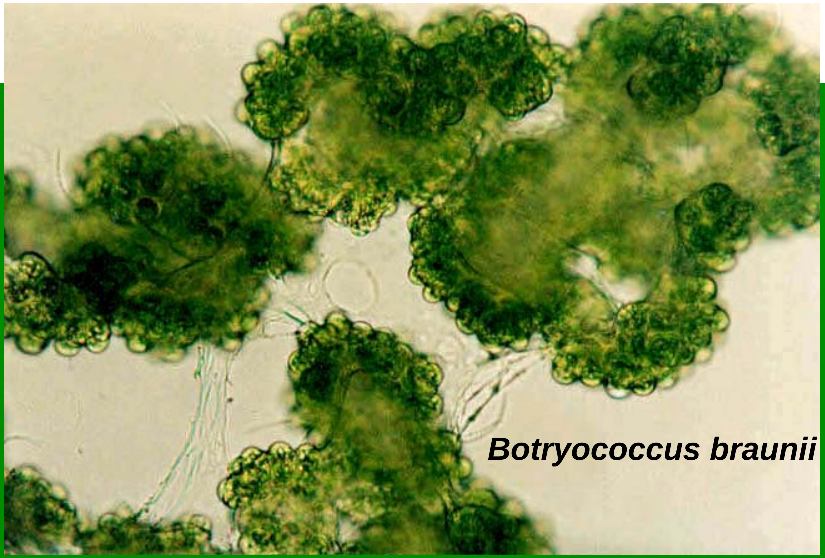
Chemo-Reactor : for conversion of algal biomass to biodiesel

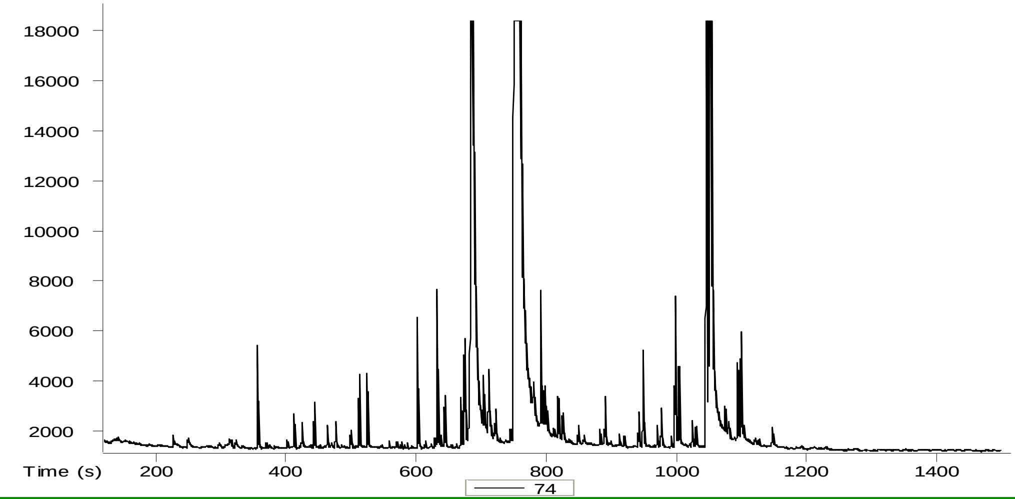
Biodiesel Production from Microalgae

Table. Biodiesel production from different algae strains with a benchtop chemoreactor:

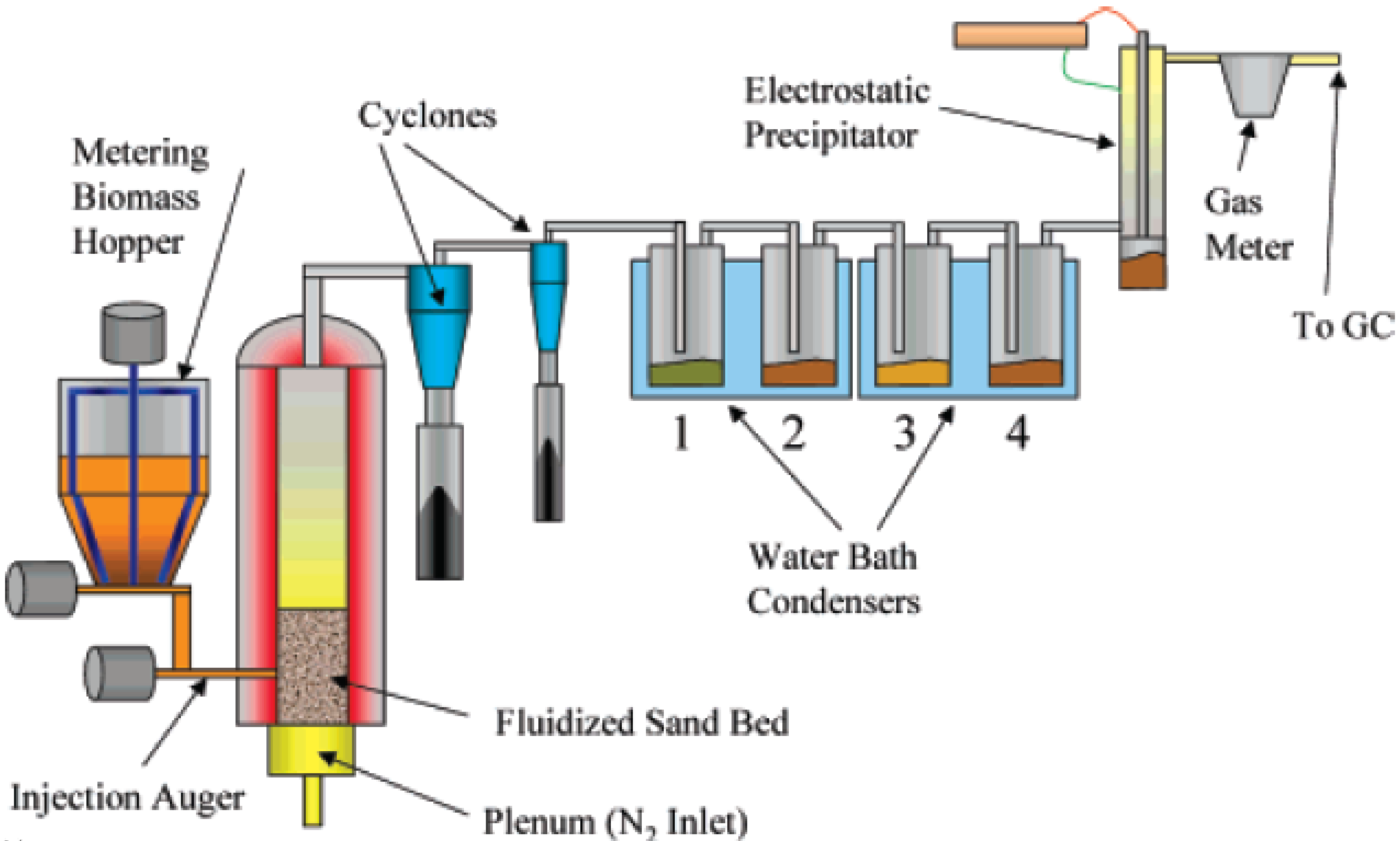
Type	Species	Oil-like yield
Protist (brown tide algae)	CCMP 1847	3%
Diatom	*Phaeodactylum tricornutum*	3%
Coccolithophorid	*Pleurochrysis carterae*	7%
Green algae	*Dunaliella spp.*	4%
Green algae	*Chlorella pyrenoidosa*	12%
Green algae	*Botryococcus braunii*	**37%**

Our preliminary results demonstrate that *Botryococcus braunii,* a green algae strain from fresh water, produces the highest diesel yield using our chemoreactor.





Fluidized bed chemoreactor being constructed



Boteng et al., *Ind. Eng. Chem. Res.*, 2007

Accomplishments and future directions

• NSF funding to examine the fate of effluent organic N: VIMS/ODU/Michigan collab. For 3 yrs

•SBIR DOE grant with Acent Laboratories to develop new technology for harvesting algae

•Submitted DARPA proposal with SRI to demonstrate production of jet fuel from algae- awaiting notification

•Commenced the building of algal raceway and tank pilot-scale facilities
  - •Collaborative with HRSD VIP plant near campus
  - •Collaborative with “algal” farmer in Hopewell, VA area
  - •Collaborative with Hopewell, VA wastewater facility

•High throughput, second-generation chemoreactor under construction

•Enter into collaboration with FL businessman who is establishing an algal-to-biodiesel enterprise

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Production and Processing Economics Estimates for Bio-diesel*

Net Cost of "Bio Crude" - $1.74/gal

Refining Costs - $1.25 - $2.50/gal

Total Cost – before profit and taxes = $4.00+/gal

* Rough estimates based upon 1996 research

Operating Cost Adjustments/Offsets

Power – Much of the power costs are already "sunk" into the water reclamation process – pumping heating, etc.

CO_2 reduction and avoidance credits can generate value

In Virginia, N and P reduction credits can generate value under state nutrient trading program

Waste Disposal costs can be eliminated or even become a profitable offset if algal biomass can be used as a fertilizer, aminal feed, or further refined into ethanol

Basic Biological Processes to Produce Algal Biomass

Bio-diesel from Algae – CO_2 Emissions

- MIT/Green Fuel Technologies, Inc.
- Green Star Products

- Colo State Univ/ Solix, Inc.
- Solazyme

- Live Fuels
- Bio King

•Blue Sun Bio-diesel

•Valcent products-Vertigro

•New Mexico State

Bio-diesel from Sewage Effluent

* Aquaflow Bionomic (NZ)

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Acknowledgements

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